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# A ROTOR FOR TESTING THE DYNAMIC PERFORMANCE OF GPS RECEIVERS

G. FIELKE and J. SILBY

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# A ROTOR FOR TESTING THE DYNAMIC PERFORMANCE OF GPS RECEIVERS

**G. FIELKE AND J. SILBY**

A-1

## SUMMARY

Evaluation of GPS User Equipment (UE) requires that a measurement be made of the error in reported position in order to gauge the performance, both static and dynamic, of the UE against the manufacturer's claims and US DoD specifications. Static error can be measured by placing the antenna of a GPS receiver over a survey point. However, it is also necessary to determine errors which may be dependent upon velocity, acceleration and higher derivatives.

A rotor has been constructed to aid in the evaluation of GPS receivers. The rotor has a ten metre arm with a mounting for a GPS antenna at the end of the arm. Angular velocity can be controlled from 0.5 to 30 rpm continuously.

The GPS antenna is mounted on the end of the rotor arm and signals are taken to the base of the radar mount via a rotary RF joint and a length of low loss Prodelin cable.

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## 1. Introduction

The Australian Defence Force (ADF) has selected the NAVSTAR/Global Positioning System (GPS) as the prime external navigation system. Joint Project Brief(JPB) 915 defines the schedule for ADF acquisition of GPS equipment.

Evaluation of GPS User Equipment (UE) requires that a measurement is made of the error in reported position in order to gauge the performance, both static and dynamic, of the UE against the manufacturer's claims and US DoD specifications.

Static error can be measured by placing the antenna of the GPS receiver over a survey marker. The reported position can then be compared with the known position. It is also necessary to determine errors which may be dependent upon velocity, acceleration and higher derivatives.

In the past, dynamic performance has been assessed by installing GPS equipment in an aircraft. The GPS equipment has been used to record the flight path of the aircraft. Contemporaneously, the aircraft has been tracked by kinetheodolites to establish ground truth. Flight trials using kinetheodolites for ground truth are expensive, dependent on weather conditions and limit velocity and acceleration values to below those claimed and specified. Processing of the results is tedious and time consuming. It was suggested in reference 1 that a rotor could be used to evaluate GPS equipment under dynamic conditions in a timely and cost efficient manner.

## 2. Design of the Rotor

The feasibility of the rotor technique is described in reference 1. A prototype rotor was constructed from an old L band radar mount to show the viability of the technique.

It was decided to constrain the length of the rotor arm to 10m. An arm was manufactured from hollow, square section mild steel and mounted on the radar mount. The rotor was driven by the 110 volt motor which came with the mount at speeds to 10 rpm in an open loop configuration. Data were recorded and analysis showed that the concept was feasible as reported in reference 1. The prototype rotor is shown in figure 1.

The results obtained with the prototype were sufficiently encouraging to warrant the construction of a rotor which consisted of a 10m counter balanced arm mounted on a turntable which is rotated at specific, accurately controlled radial velocities in the range 0.5 rpm to 30 rpm.

The arm of the rotor was constructed from aluminium mast extrusion and braced with stainless steel wire rope. It was mounted on the L band radar mount. A standard 2 pole, 7.5kW, 415 volt, 50hz squirrel cage motor was used to drive the rotor arm via the 180:1 reduction gear of the radar mount.

The GPS antenna is mounted on the end of the rotor arm and signals are taken to the base of the radar mount via a rotary RF joint and a length of low loss (Prodlin) cable.

The final version of the rotor is shown in figure 2.

The radar mount was originally fitted with coarse and fine synchro resolvers for measuring the shaft position. It was decided to use these synchros to record shaft position while the rotor is operating. A ten bit synchro to digital converter was connected to the coarse synchro.

The synchro to digital converter has an uncertainty of +/- 0.5 LSB. Uncertainty in the measured shaft angle is, therefore, 360/1024 degrees. This allows the position of the end of the rotor arm to be estimated within 0.06m which is two orders better than the expected accuracy of the GPS receivers which will be tested.

If greater accuracy is required, either a 12 bit shaft encoder or a further synchro to digital converter on the fine synchro will be required.

3. **Control of the Induction Motor**

Speed control of an induction motor is best achieved by varying the frequency of the supply voltage. The voltage is varied in proportion to the frequency to keep the voltage/frequency ratio constant. This was achieved by using a commercially available, three phase supply which is pulse width modulated.

4. **The Control Loop**

Control was achieved by mounting a 60 tooth gear wheel on the motor. A magnetic pick up generates a pulse as each tooth passes it. These pulses are used to calculate the speed of the motor shaft and hence the speed of the rotor arm. A microprocessor is used to count the pulses from the motor gear and reference pulses are used to drive the motor via the commercial supply. Any difference in pulse count between the reference pulses and those from the gear on the motor will result in an error signal which will be corrected by the microprocessor.

A block diagram of the system is shown in fig.3.

With reference to fig.3:

A 100Hz signal from a crystal oscillator or some other stable source is used as a reference signal for the controller.

The controller compares the frequency of the reference source with the frequency of the pulses derived from the magnetic pick up. The output frequency and voltage of the inverter is then adjusted to reduce the difference between the two frequencies to zero.

5. **Method of Testing the Control Loop**

The rate of rotation of the rotor is set by a digital word which is input from the front panel of the controller. The true angular velocity could be determined by measuring the time taken for the arm to complete a number of revolutions. An accurate measurement of time would have been difficult to achieve by direct methods.

A source of accurate 1Hz pulses was available from the Surveillance Research Laboratory Time and Frequency Standard and it was decided to use these pulses to interrogate the synchro to digital converter and measure the accumulation of angular movement over a period of time. The ratio of true angular velocity to nominal angular velocity was then calculated. The rational for this method of measurement is to be found in Appendix I.

The arm was rotated at nominal rates of 1,5,10,15, and 20 revolutions per minute(rpm). These were chosen so that each revolution would take an integer number of seconds to complete. Thus, if the shaft angle is recorded once per second, the recorded angles should repeat each 60/r seconds where 'r' is the angular velocity in rpm. Any variation in angular velocity will result in a change in these recorded angles.

The shaft angle was recorded each 60/r seconds while the shaft was rotated for about 400 revolutions. Regression coefficients for angle against revolutions were calculated and hence, $\delta\emptyset/\emptyset$.

The true angular velocity can be calculated by the relationship:

True angular velocity = Nominal angular velocity($1+\delta\varnothing/\varnothing$)

The value of $\delta\varnothing/\varnothing$ was found to be approximately -1E-4 for each rate of rotation tested. This value had an average value of -1.11E-4 with minimum and maximum values of 1.04E-4 and 1.3E-4.

It can be concluded that the arm rotates one part in $10^4$ more slowly than the nominal rate of rotation.

The loop constants of the controller were set to give the loop a critical damping factor. The response to a step input is to give one overshoot and one undershoot at the output. The response was determined by observing the error voltage with a storage oscilloscope.

## 6. Test Results

### 6.1 Constant Velocity

The rotor was maintained at a constant angular velocity for approximately 15 minutes. A measurement of the shaft angle was taken once per second. The angular velocities were chosen such that one revolution would be completed in an integer number of seconds. Any deviation from the nominal velocity would be revealed by the measurement of angle swept per unit time.

The results showed that the rate of rotation was less than the nominal by parts in $10^4$. This data is shown in the following table.

| rpm | time of rotation | measured lag | $\delta\varnothing/\varnothing$ |
|---|---|---|---|
| 1 | 15 min | 0.7 degrees | 1.30E-4 |
| 5 | 15 min | 2.8 degrees | 1.04E-4 |
| 10 | 13 min | 4.9 degrees | 1.05E-4 |
| 15 | 14 min | 8.1 degrees | 1.07E-4 |
| 20 | 14 min | 11.3 degrees | 1.12E-4 |
| | | Average $\delta\varnothing/\varnothing$ ==> | 1.11E-4 |

The above measurements were taken with the wind gusting to 15 knots.

### 6.2 Acceleration

The rotor was accelerated from rest to predetermined angular velocities of 1,10,20, and 30 rpm. It was discovered that the maximum attainable angular velocity was 28 rpm. The controller parameters were set to force the rotor to accelerate to the desired velocity in 40 seconds. The parameters were optimised to give the required acceleration characteristic at a terminal angular velocity of 10 rpm. The speed/time characteristics of the rotor are shown in figs 4 - 7.

## 7. GPS Measurements

The antenna of a GPS receiver is mounted on the end of the rotor arm and connected to the receiver at the base of the rotor via a length of low loss Prodlin coaxial cable.

All of the recording and control equipment is housed in a caravan some 20 metres from the rotor. Data is collected from the data port

of a GPS receiver and recorded on a computer. The data port of the receiver is connected to the computer by a length of screened cable, the data is normally transmitted at RS422 levels. As well as the data from the GPS receiver, Universal Time Coordinated (UTC) and shaft angle of the rotor are also recorded. The coordinates of the centre of the rotor have been supplied by the Australian Land Information Group (AUSLIG). The position reported by the GPS receiver is compared

with the truth data calculated from the dimensions of the rotor arm and the shaft angle.

## 7.1 Preliminary Results

Data have been collected from a Magnavox MX4400 receiver and a Collins UH60 receiver with the rotor shaft rotating at angular velocities from 1 to 5 rpm. Both of these receivers are specified to an acceleration of 2g. The position recorded from these receivers was plotted with respect to the centre of the rotor. These plots are shown in figs 8 - 10.

These figures show the effect of different filters. Figures 8 and 9 show the effect of changing the filter in the Magnavox receiver and figure 10 shows that the UH60 receiver has been optimised for medium dynamics.

The above named receivers are two channel sequencing receivers which sample each satellite in turn. They must predict ahead the range measurements to the solution time. A test of this nature will test the ability of the receiver to predict ahead using its calculations of range rate.

Work on analysis software is proceding.

## 8. Other Developements

A contract was let to the Queensland University of Technology to study methods of using the rotor data for analysis of GPS receiver performance and for filter identification. The University has produced software to assess receiver performance and to determine the filter characteristics. This has been tested on data from the rotor and shows promise of being a useful tool.

This work is described in references 2,3, and 4.

## 9. Conclusions

A rotor with a 10 metre arm has been constructed which can be rotated at speeds from 0.5 to 30 rpm. The speed of rotation is tightly controlled allowing the rotor to be used for testing the accuracy of position and velocity reporting of GPS receivers. Software is being developed to analyse data collected from the rotor.

The Queensland University of Technology has developed techniques for using the data to determine filter characteristics of GPS receivers.

## APPENDIX I

### Measurement of Angular Velocity

If we designate $w$ = angular velocity
and $T$ = time taken for one revolution

We can say that $w = 2\pi/T = 2\pi f$ where $f$ = frequency in Hertz

Differentiating
$$dw = -2\pi T^{-2} dT$$
$$= -w dT/T$$
ie: $$dw/w = -dT/T$$

Time can be measured from the angle traversed, ie:

$$dT/T = d\emptyset/\emptyset$$

Approximating the differential to the difference:

$$\delta w/w = -\delta T/T = \delta\emptyset/\emptyset$$

Where $\delta\emptyset$ = difference between the measured angle traversed and the expected angle.

If we designate the rate of turn of the arm as r rpm and measure the shaft angle each 60/r seconds, a graph of shaft angle against number of revolutions can be plotted. The slope of the line is then equal to $\delta\emptyset$ in units of degrees per revolution. $\delta\emptyset$ can now be divided by 360 to obtain $\delta\emptyset/\emptyset$ which is dimensionless. The true angular velocity can now be found from the relationship:

$$w_{true} = w_{nom}(1 + \delta\emptyset/\emptyset)$$

## REFERENCES


| | | |
|---|---|---|
| 1. | Gubbay, J.S. | GPS User Equipment Evaluation Technique Using a Rotor Mounted Antenna SRL |
| 2. | Queensland University of Technology | GPS Filter Identification for UE Identification (FEB 89) |
| 3. | Queensland University of Technology | GPS Filter Identification User Equipment Evaluation (MAR 90) |
| 4. | Queensland University of Technology | Simulation of RATS on NAVSIM Simulation Software (MAY 90) |
| 5. | Queensland University of Technology | GPS Filter Identification and User Equipment Evaluation (JUN 90) |

Figure 1. Prototype rotor

Figure 2. Finished rotor

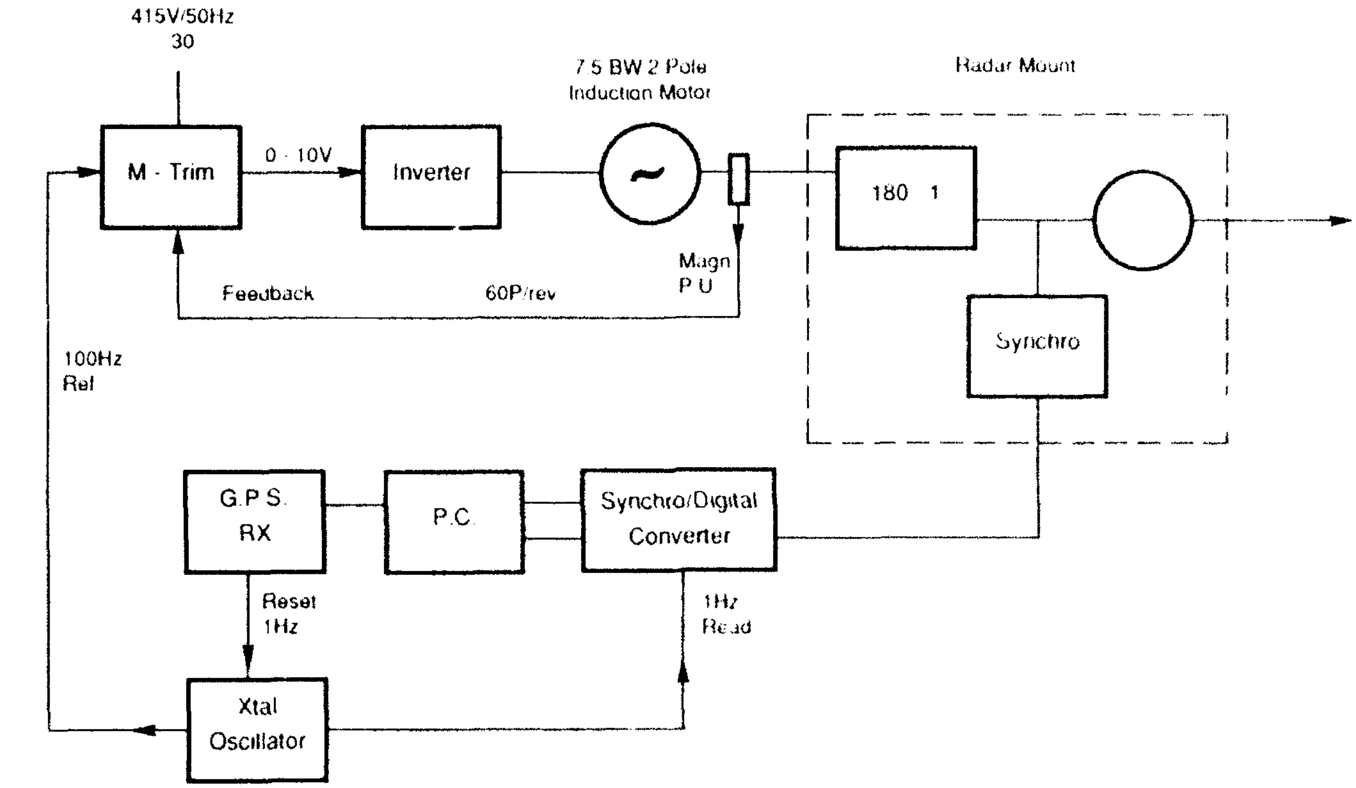



Figure 3 System block diagram

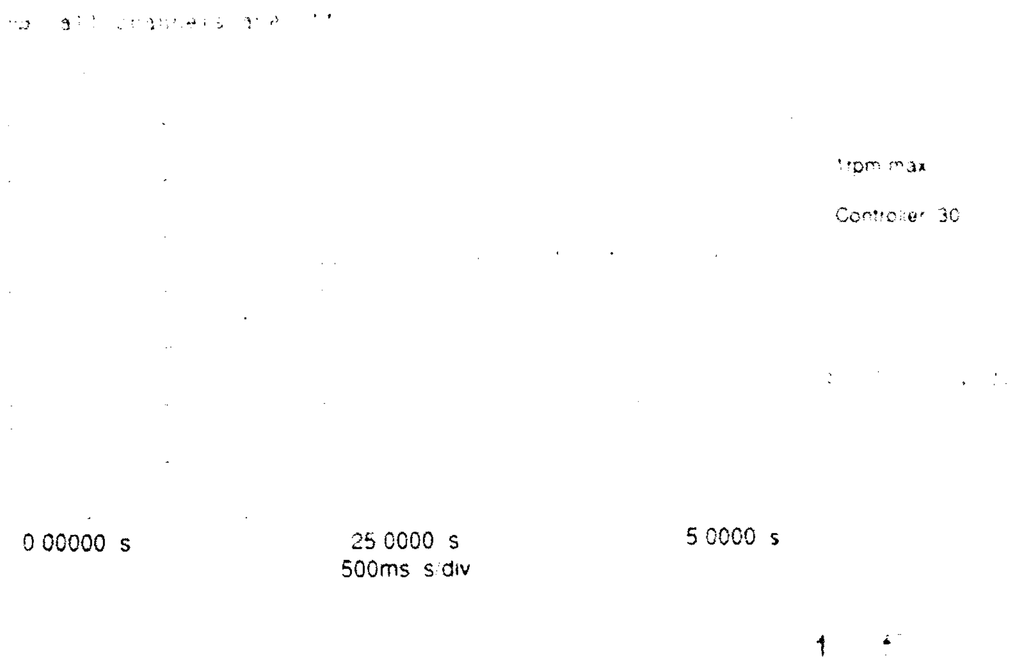



Figure 4. Acceleration characteristic - 1rpm

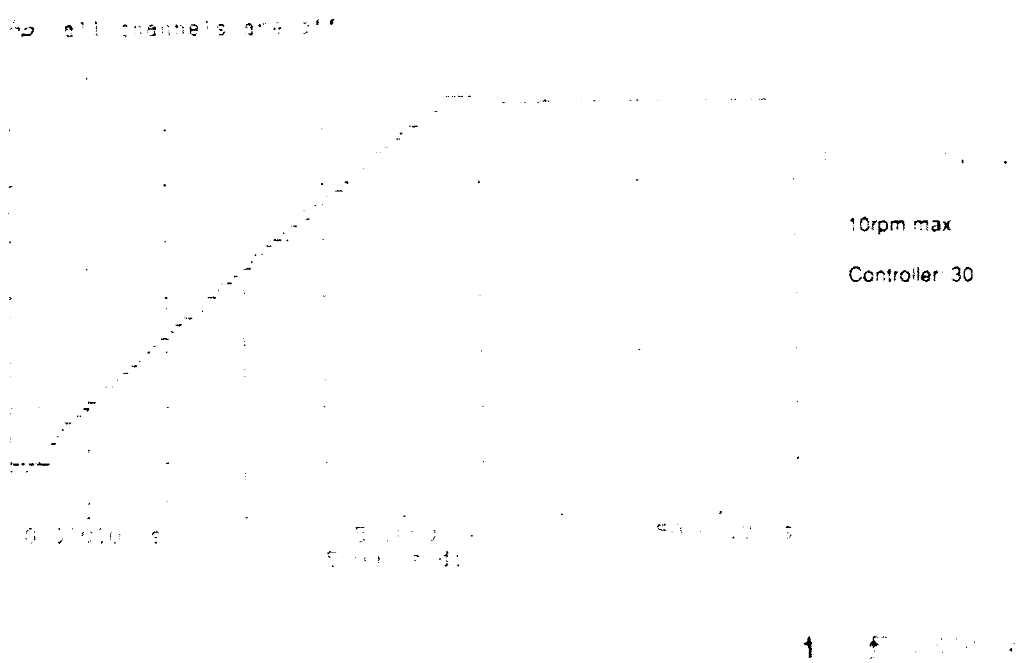



Figure 5. Acceleration characteristic - 10rpm

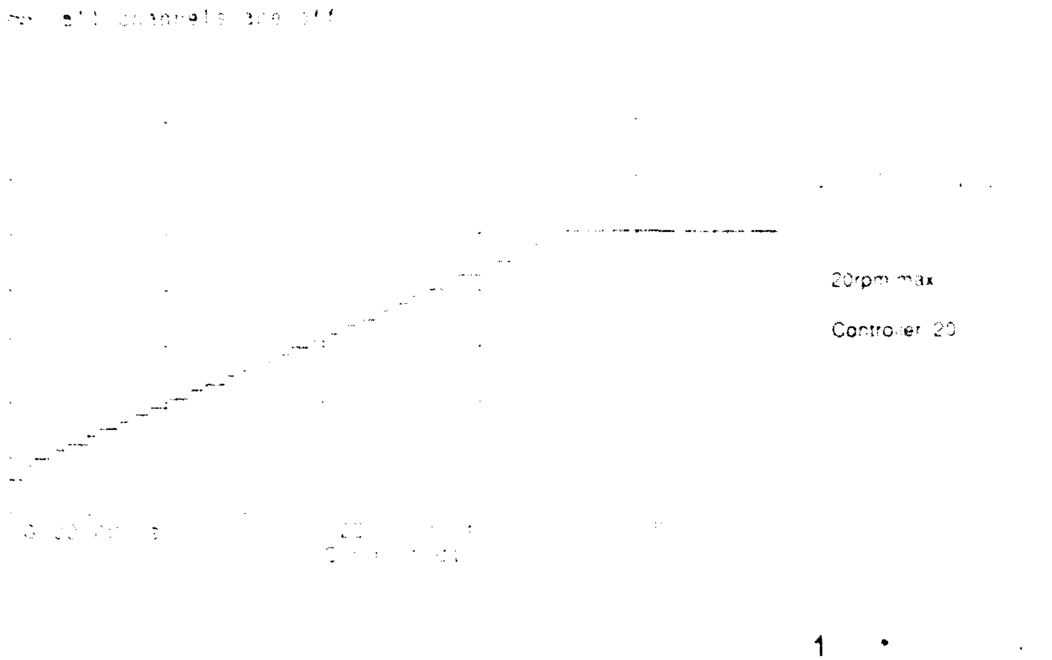



Figure 6. Acceleration characteristic - 20 rpm

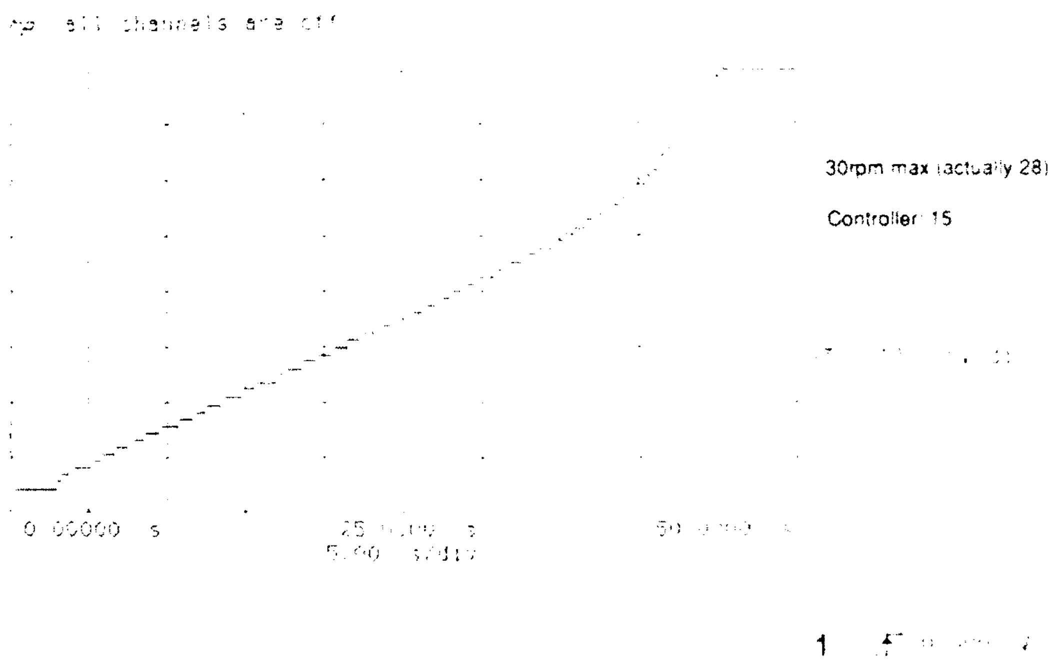



Figure 7. Acceleration characteristic - 30rpm

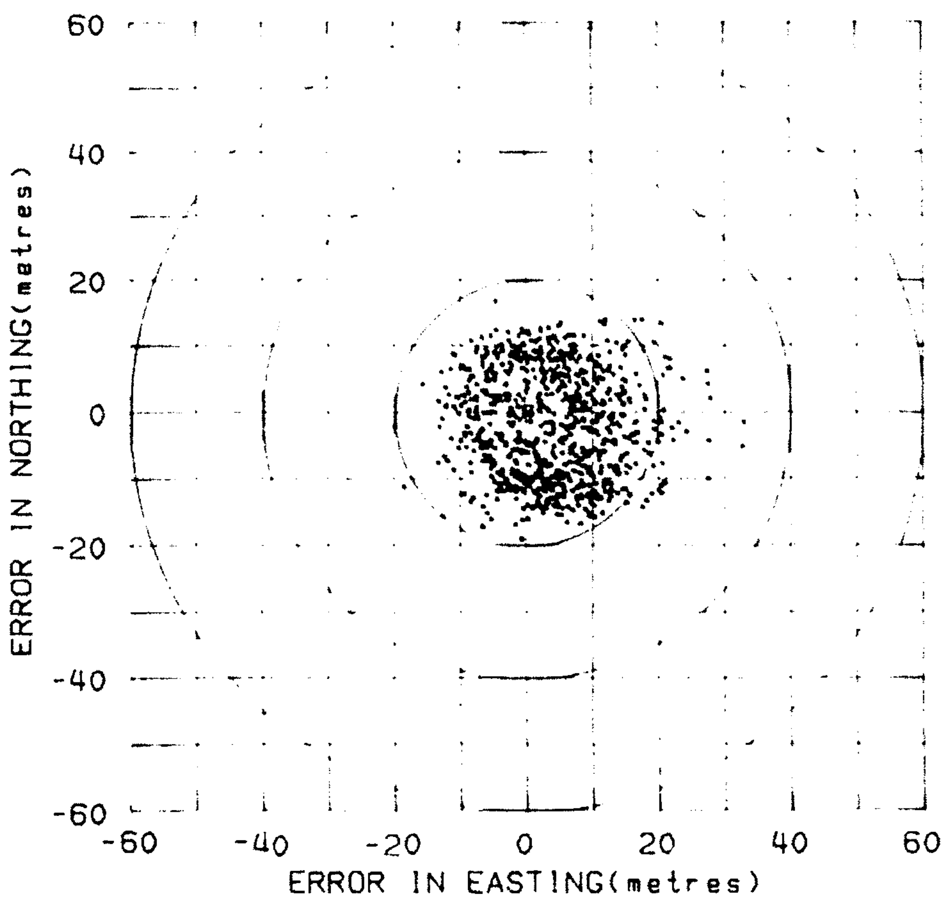
# 5 rpm FILTER 2.2

Receiver Type: MX4400

| EAST | | NORTH | |
|---|---|---|---|
| Mean: | 3.1 | Mean: | -1.3 |
| Standard deviation: | 8.4 | Standard deviation: | 7.9 |

Number of data points: 763

HDOP = 2.[illegible]




Reference position (WGS84 coordinates)

EAST: 283134.917
NORTH: 6154021.780
ZONE: 54

Figure 8. Track plot - Magnavox MX440 - 5rpm - filter 2.2

# 5 rpm FILTER 2.8

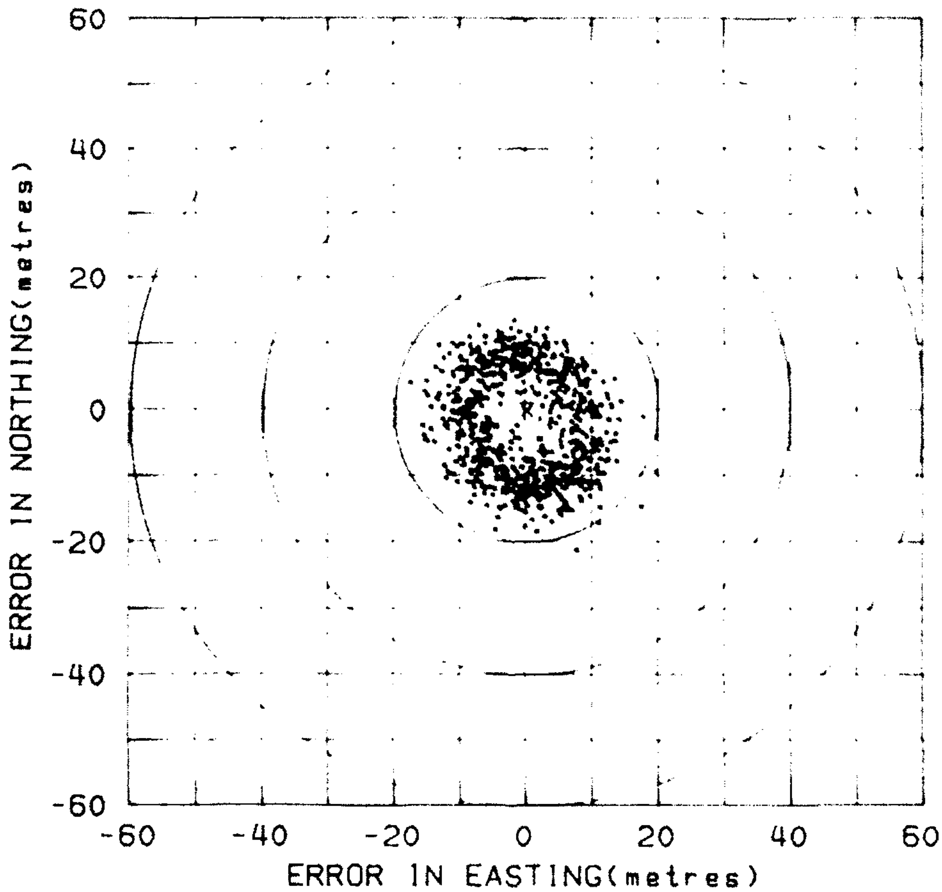
Receiver Type: MX4400

EAST
Mean: -1.0
Standard deviation: 7.0

NORTH
Mean: -1.8
Standard deviation: 7.9

Number of data points: 771

HDOP = [illegible]




Reference position (WGS84 coordinates)

EAST: 283134.917
NORTH: 6154021.780
ZONE: 54

Figure 9. Track plot - Magnavox MX4400 - 5rpm - filter 2.8

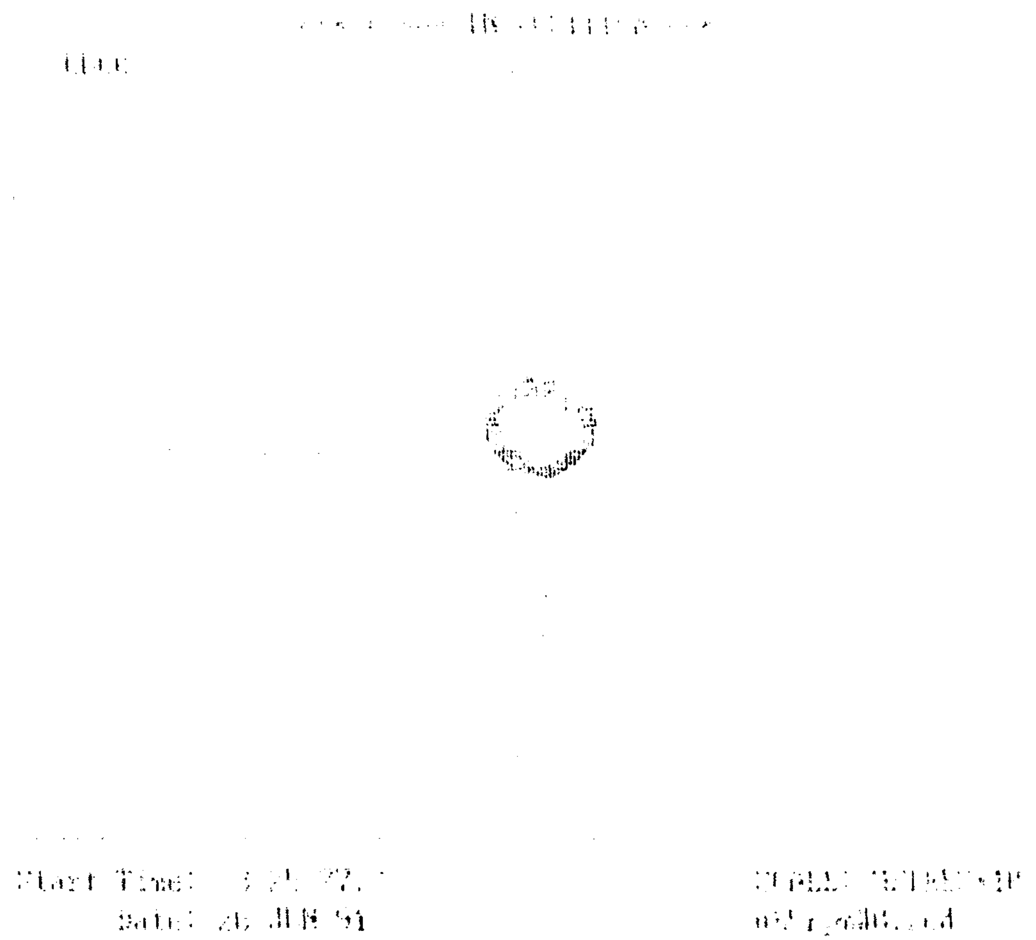


Figure 10. Track plot - UH60 - 5rpm

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